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Potential Savings for Cote d'Ivoire, Ghana, Nigeria and Senegal from BUENAS modeling

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Acknowledgements

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Introduction

The Economic Community Of West African States (ECOWAS) Regional Centre for Renewable Energy and Energy Efficiency (ECREEE) and the Super-efficient Equipment and Appliance Deployment (SEAD) initiative, has announced their commitment to work together to accelerate the pace of energy efficiency improvement for appliances and equipment in West Africa in support of the UN Secretary General's Sustainable Energy for All initiative[1]. In this joint effort, SEAD is providing technical and analytical support for the development of policies and standards that can accelerate efficiency, energy savings, energy access and—consequently—economic development throughout the ECOWAS region. This report aims at providing the baseline and potential achievable savings through the implementation of energy efficiency Standards and Labelling programs.

Our analysis suggests that the ECOWAS region could save over 63 terawatt hours (TWh) of electricity per year in 2030, equivalent to the electricity produced by roughly twenty 500-MW power plants, by adopting best practice efficiency standards for clothes washers, fans, refrigerators, room air conditioners, lighting, televisions, standby power and motors.

These preliminary results are estimated using a spreadsheet model adapted from the 2008 version of the Bottom-Up Energy Analysis System (BUENAS)[2], a stock-accounting model that calculates energy demand at the technology level and projects efficiency improvement based on specific targets determined to be achievable in the ECOWAS region (McNeil et al., 2008a). Impacts of policy actions towards market transformation are calculated by comparing energy demand in the "Business-As-Usual" (BAU) case to a specific policy case where Minimum Efficiency Performance Standards (MEPS) enter into effect in 2015. This analysis covers Cote d'Ivoire, Ghana, Nigeria, and Senegal, which together account for 85% of electricity consumption of the fifteen-country ECOWAS region (ADEME, 2011). The following table provides a summary of the scope of the study:

Table 1 End uses covered in the study by sector

	Residential	Commercial	Industry
Air Conditioning	▓	▓	
Cooking			
Fans	▓		
Lighting	▓		
Refrigerators & Freezers	▓		
Space Heating			
Standby	▓		
Television	▓		
Laundry	▓		
Water Heating			
Distribution Transformers			
Motors			▓

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[1] More information available at:
http://www.superefficient.org/en/Resources/~/media/Files/120617_SEAD_ECREEE_PR_FINAL.pdf
[2]None of the West Africa sectors are modeled in the more recent BUENAS LEAP framework (McNeil et al., 2012).

Methodology.

BUENAS consists of three modules, as shown in Figure 1. Each module is described in the following sections.
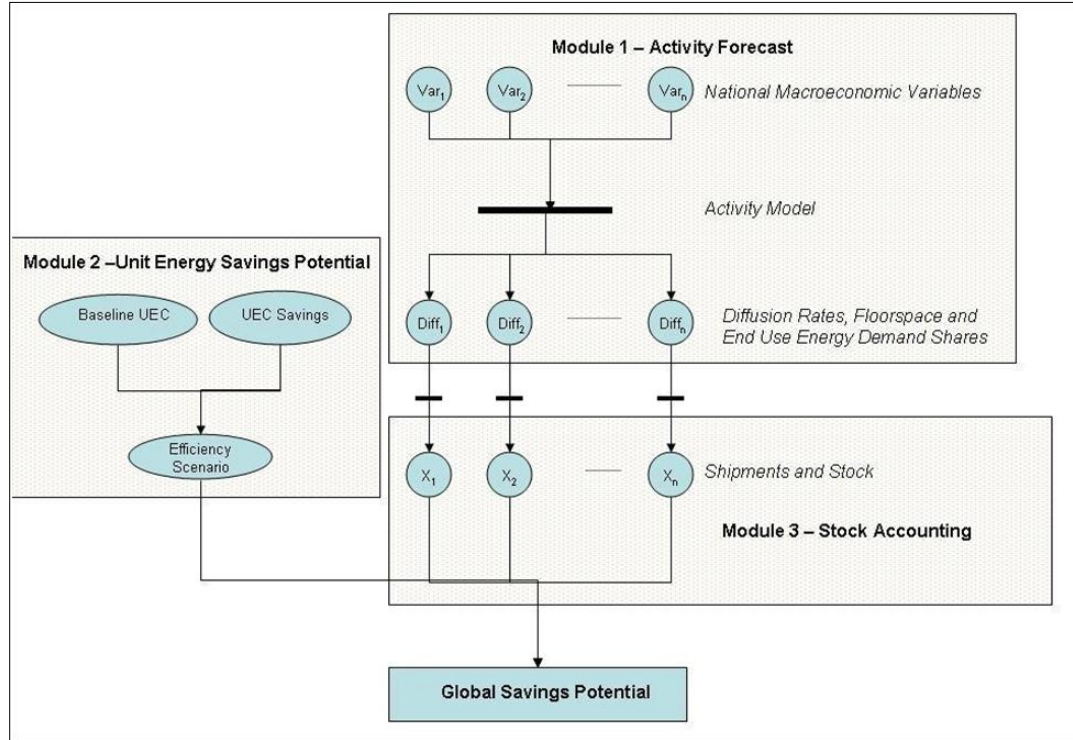
Figure 1. BUENAS analytical components

Module 1: Activity Forecast.

Few household surveys on appliance ownership (diffusion[3]) have been conducted in the ECOWAS region (an example of a survey conducted in Ghana is Constantine and Denver (1999)). Even if appliance ownership data were available at a given point in time, it is difficult to forecast its evolution without having to making a simplistic assumption on the final point. In order to predict the saturation of appliances in a more generic way, LBNL has developed a macro-economic model that relies on national variables such as GDP/capita, urbanization, electrification, etc. to estimate the number of appliances per household (more details available in (Letschert and McNeil, 2009)). The general form of the diffusion equation is given below:

$$\text{Diffusion}(y) = \frac{\alpha}{1 + \gamma \times \exp(\beta_1 \times I(y) + \beta_2 \times U(y) + \beta_3 \times E(y))} \qquad \textbf{Equation 1}$$

- $I(y)=monthly$ household income (*GDP* per household) in year (y)
- $U(y)=$urbanization rate in year (y)

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[3] Diffusion is defined as the total number of a given appliance in the stock divided by the number of households in the country.

- *Elec(y)* = electrification rate in year (y)

Urbanization is replaced by a climate variable in the case of air conditioner diffusion, see (McNeil and Letschert, 2007) for more details.

We use the household survey in Ghana from 2003 to calibrate our diffusion curves (Van Buskirk, 2004). We only find a significant difference for refrigerators, where preliminary data suggests that 38 to 45% of households own a refrigerator whereas the model forecasts only 22% of appliance ownership. Instead of applying a constant factor in every year to correct for the difference, we shift the curves forward on the time-axis to match the data (Fig. 2). We find that the saturation happens 7 years earlier than what the model predicts. This can be due to real price of appliances dropping over time and making appliances more affordable at lower income than what is predicted with constant prices.

Note: Ghana saturation has been shifted 7 years forward

Figure 2. Refrigerators penetration forecast.

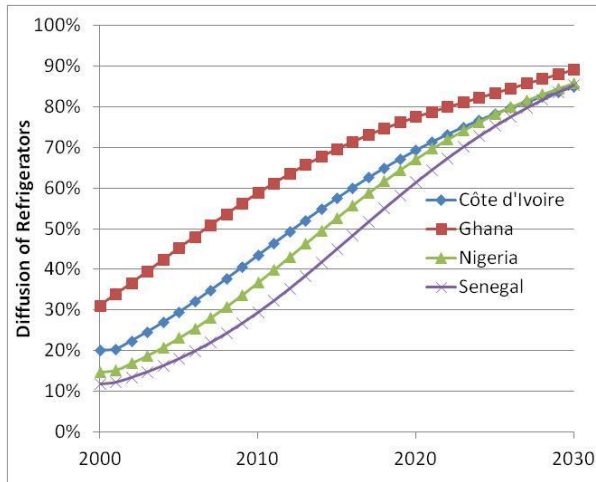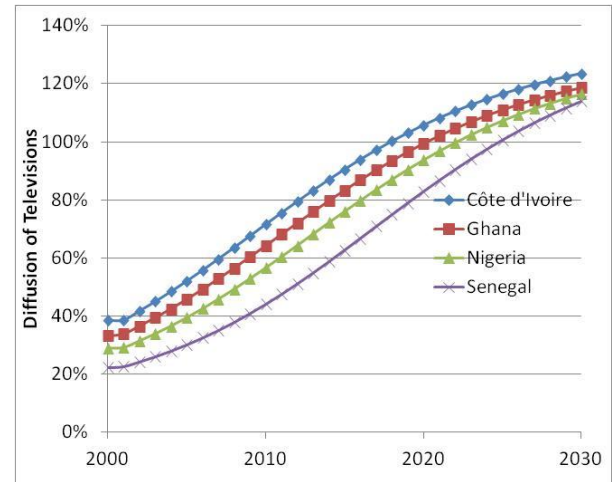**Figure 3. Televisions penetration forecast.**

In the commercial sector, floor space and cooling intensity are based on an econometric model driven by GDP per capita and employment rates (McNeil et al., 2008). In Ghana, we have some evidence that the commercial sector represent 80-90% of the country air conditioning (AC) consumption[4]. We use the modeled energy consumption from the 2008 BUENAS model to corroborate this statement. We find that indeed, when comparing with the residential modeled energy consumption, almost 90% of the consumption and savings are found in the commercial sector. If we assume double hours of use in the commercial sector compared to the residential sector, we find that there are three to four more room air conditioners in the commercial sector than found in the residential sector. We assume the same factor for all the ECOWAS countries. In the rest of the paper, the two sectors are lumped together under the air conditioner category. Unfortunately, the data for other commercial end uses are too scarce to derive meaningful results.

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[4] Personal communication with Robert Van Buskirk, Program Manager at LBNL, June 1st 2012.

In the industry sector, we assume that motors represent a constant fraction of the sector consumption. We forecast the industry sector consumption using a 3% annual growth rate as forecasted by the International Energy Outlook (EIA, 2011).

Table 2 lists the variables used for each sector in the activity model:

Table 2 BUENAS Macroeconomic Activity Drivers (2010 Estimates)

Residential	Unit	Côte d'Ivoire	Ghana	Nigeria	Senegal
Monthly Income per household	$2000	$402	$132	$165	$521
Electrification rate	%	74%	70%	65%	54%
Urbanization	%	48%	49%	52%	55%
Cooling Degree Days	C	2937	2949	3111	3379
Commercial					
GDP per capita	$2005	883	441	740	801
Employment	%	88%	88%	88%	88%
Surface Area	Million m^2	32.2	44.4	224.9	22.0
Industry					
Industry electricity consumption	GWh	997	2943	3249	571

Source: BUENAS 2008 and IEA for Industry

Module 2: Unit Energy Savings Potential.

The second major element of the analysis is to create a realistic scenario of potential efficiency achievements through the implementation of MEPS programs in the ECOWAS region. We assume that a reasonable timeframe to develop this set of regulations would lead the MEPS to enter into effect in 2015.

Data on energy consumption are scarce in the ECOWAS region. We have to rely on partial data, or data from other countries to estimate the baseline efficiency and energy consumption of the appliances we study. We make adjustments for the ECOWAS region context, as described below.

Some market transformation efforts have been conducted in Ghana, specifically on refrigerators (Van Buskirk et al., 2007). The field survey showed that refrigerators in Africa consume a lot more than refrigerators in developed countries. This is due to a variety of factors, including ambient temperature, humidity, unreliable electricity supply, etc. but mostly the age of the appliance. It has been found that a large fraction of the market is made up of second-hand refrigerators coming from Europe. As a consequence, the appliances efficiency is deteriorated compared to new appliances (deteriorated insulation, compressor efficiency, refrigerant leak, etc)… For the purpose of the study, we use the field consumption measured in the study of 1140 kWh/year as our baseline (Van Buskirk et al., 2007). In the efficiency case, we assume that the field consumption is reflected by the rated energy consumption (EC, 2010).

For televisions, while marketing firms forecast the phase out of CRT technology by 2015, we assume that there will still be a market for them in the ECOWAS region. We assume that 30% of televisions sold on the market in 2015 are CRTs (70% LCD).

Table 3 summarizes the efficiency characteristics of the baseline units and achievable targets assumed for key energy users covered in this study.

Table 3 Summary of Unit Level Assumptions for ECOWAS Countries

RESIDENTIAL	Baseline Technology/ Efficiency	Baseline UEC (kWh/yr)	Efficient Technology/ Efficiency	Efficient UEC (kWh/yr)	Reference
Clothes Washers	Front Load, estimate from (Department of Minerals and Energy, 2003)	281.0	Level A	195.8	(Unlimited Energy Resources (pty) ltd, 2012)
Fans	70 W	102.2	BLDC Motor, efficient blades (53%)	48.0	(Sathaye et al., 2012)
Fluorescent Ballasts	Magnetic Ballast	69.1	Electronic Ballast	60.3	(McNeil et al., 2008)
Incandescent Lamps	15 Lm/W	87.6	60Lm/W (CFL)	21.9	(McNeil et al., 2008)
Refrigerators	1 door, inefficient, possibly second-hand appliances	1140.0	1 door, EU C Level	401.0	(Unlimited Energy Resources (pty) ltd, 2012)
Room Air Conditioners[*]	2.8 SEER, 3.5kW CC	1800.0	5 SEER, 3.5kW CC	1008.0	Ghana MEPS and (Shah et al., 2012)
Standby Power	EU pre-standard average	18.4	EU tier-2 standard average	3.6	(EC, 2008)
Televisions	Mix of technologies (CRTs, LCD)	65.6	LCD, CCFL technology	38.5	Assumptions derived from (Park et al., 2012)
INDUSTRY	Baseline Technology/ Efficiency	Baseline Efficiency (%)	Efficient Technology/ Efficiency	Efficiency Target (%)	Reference
Motors 0.75-7.5 kW (1.1 kW)	IE1	76%	NEMA Premium	87%	Assumption
Motors 7.5-75 kW (11 kW)	IE1	88%	NEMA Premium	93%	Assumption
Motors > 75 kW (110 kW)	IE1	94%	NEMA Premium	96%	Assumption

[*]Includes room air conditioners used in commercial buildings

Module 3: Stock accounting.

The stock turnover analysis calculates the sales in every year of the forecast period using increase in the stock and retirements calculated from past sales. The following equations describe the calculations performed in the BUENAS framework:

$$\text{Sales(y)}=\text{Stock(y)}-\text{Stock}(y\text{-}1)+\sum\nolimits_{age}\text{Ret(age)}\times\text{Sales(y-age)} \qquad \textbf{Equation 2}$$

- *Stock (y)* = Number of units in operation in year *y*
- *Ret(age)* = probability that a unit will retire (and be replaced) at a certain age

The stock is calculated as the product of the appliance diffusion rates and the number of household in every year:

$$\text{Stock(y)} = \text{Diffusion (y)} \times \text{HH(y)} \qquad \textbf{Equation 3}$$

- *Diffusion (y)* = Number of units (owned and used) per household in year *y*
- *HH(y)* = Number of households in year *y*.

The following table presents the assumptions that were used for the average appliance lifetimes (McNeil et al, 2008):

Table 4 Lifetime assumed for covered end uses

End Use	Lifetime (years)
Clothes Washers	15
CFLs	5
Fans	10
Fluorescent Ballasts	15
Incandescent Lamps	1
Motors 0.75-7.5 kW (1.1 kW)	12
Motors 7.5-75 kW (11 kW)	15
Motors > 75 kW (110 kW)	20
Refrigerators	15
Room Air Conditioners	12
Standby Power	8
Televisions	10

When sales are available they are implemented directly as a direct input into the model. In our study, sales are available for light bulbs through the En.lighten initiative (En.lighten, 2012).

Table 5 Estimated Sales by country and end use in the residential sector

End Use	Country	Sales in Millions		Annual Growth Rate
		2010	2030	%
Clothes Washers	Côte d'Ivoire	0.11	0.3	5.4%
	Ghana	0.13	0.4	6.5%
	Nigeria	0.44	2.2	8.3%
	Senegal	0.02	0.2	12.5%
Fans	Côte d'Ivoire	0.2	0.4	3.3%
	Ghana	0.3	0.6	3.2%
	Nigeria	1.3	2.7	3.6%
	Senegal	0.1	0.2	4.4%
Fluorescent Ballasts	Côte d'Ivoire	0.3	0.6	3.5%
	Ghana	0.4	0.7	2.8%
	Nigeria	2.0	3.8	3.2%
	Senegal	0.2	0.5	4.5%
Residential Lamps	Côte d'Ivoire	16.8	33.6	3.5%
	Ghana	13.7	26.5	3.3%
	Nigeria	174.2	374.6	3.9%
	Senegal	15.1	42.6	5.3%
Refrigerators	Côte d'Ivoire	0.1	0.2	3.7%
	Ghana	0.2	0.4	3.1%
	Nigeria	0.9	1.9	4.0%
	Senegal	0.1	0.2	5.2%
Air Conditioners	Côte d'Ivoire	0.03	0.1	5.1%
	Ghana	0.04	0.1	3.5%
	Nigeria	0.18	0.4	4.0%
	Senegal	0.03	0.1	5.3%
Standby Power	Côte d'Ivoire	0.3	0.6	4.3%
	Ghana	0.4	0.7	3.2%
	Nigeria	1.8	3.6	3.6%
	Senegal	0.2	0.5	4.4%
Televisions	Côte d'Ivoire	0.2	0.5	3.9%
	Ghana	0.3	0.7	4.0%
	Nigeria	1.5	3.6	4.6%
	Senegal	0.1	0.3	6.0%

In the industry sector, we use IEA estimates of total sector consumption for each country (IEA, 2012). Motors energy consumption varies between 60 to 70% of total industry consumption. With the assumption that there is no heavy industry which consumes a lot of electricity (i.e steel, aluminum) in the ECOWAS region, we assume that the motors represent 70% of the industry energy consumption (McNeil et al., 2008b). We forecast sector consumption using the IEO estimate of annual growth rate for non-OECD countries of 3% (EIA, 2011). The product class market shares are assigned to each representative class so that they are inversely proportional to their size as shows in the following table.

Table 6 Product Class Market Shares for Motors for all ECOWAS countries

End Use	Product Class	Market Shares (Constant)
Motors	0.75-7.5 kW (1.1 kW)	90.1%
	7.5-75 kW (11 kW)	9.0%
	> 75 kW (110 kW)	0.9%

Regional Savings Potential Methodology

We use the sales forecast as an input to calculate the energy consumption of the stock according to base case efficiency, efficiency market share shifts as a result of the MEPS, and turnover of the equipment.

The baselines and targets determined in Table 3 are estimated in the year of the standard and are assumed to be constant throughout the forecast period. By assuming frozen efficiency in the BAU as well as the policy case, we implicitly assume that the market-driven efficiency improvement that would happen in the BAU would also happen in the policy case (EFF scenario), i.e., the potential savings are constant.

We calculate National Energy Savings ($\Delta E(y)$) in each year from 2015 to 2030 by comparing the national final energy consumption $E(y)$ of the end use under study in the BAU to the policy case, according to:

$$\Delta E(y) = E_{BAU}(y) - E_{EFF}(y) \qquad \textbf{Equation 4}$$

We calculate final energy demand according to unit energy consumption of equipment sold in previous years:

$$E_{BAU} = \sum_{age} Sales(y\text{-}age) \times UEC_{BAU}(y\text{-}age) \times Surv(age) \qquad \textbf{Equation 5}$$

- *Sales (y)* = unit sales (shipments) in year *y*
- *UEC(y)* = unit energy consumption of units sold in year *y*
- *Surv(age)* = probability of surviving to *age* years

The survival function and retirement function are related by:

$$Surv(age) = 1 - \sum_{age} Ret(age) \qquad \textbf{Equation 6}$$

The calculated BAU[5] and potential savings are presented in Figure 5. This graph shows the energy reduction wedges at the regional level. Because a lot of appliances have yet to be purchased in this region, the electricity demand in the BAU increases substantially (4.2% per year). By 2030, the implementation of MEPS in 2015 could reduce electricity consumption of the products studied by 50%. Also, the forecasted impacts from MEPS reduce the annual growth of energy demand to a mere 0.5% percent per year, almost canceling the growth in energy demand due to population and appliance ownership.

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[5] BAU electricity demand was found to exceed IEA 2009 energy consumption data for the residential sector for these countries, possibly as a result of shortages, which are not accounted for in our analysis. In this analysis, the demand modeled is what would be met if the electricity were available 24/7
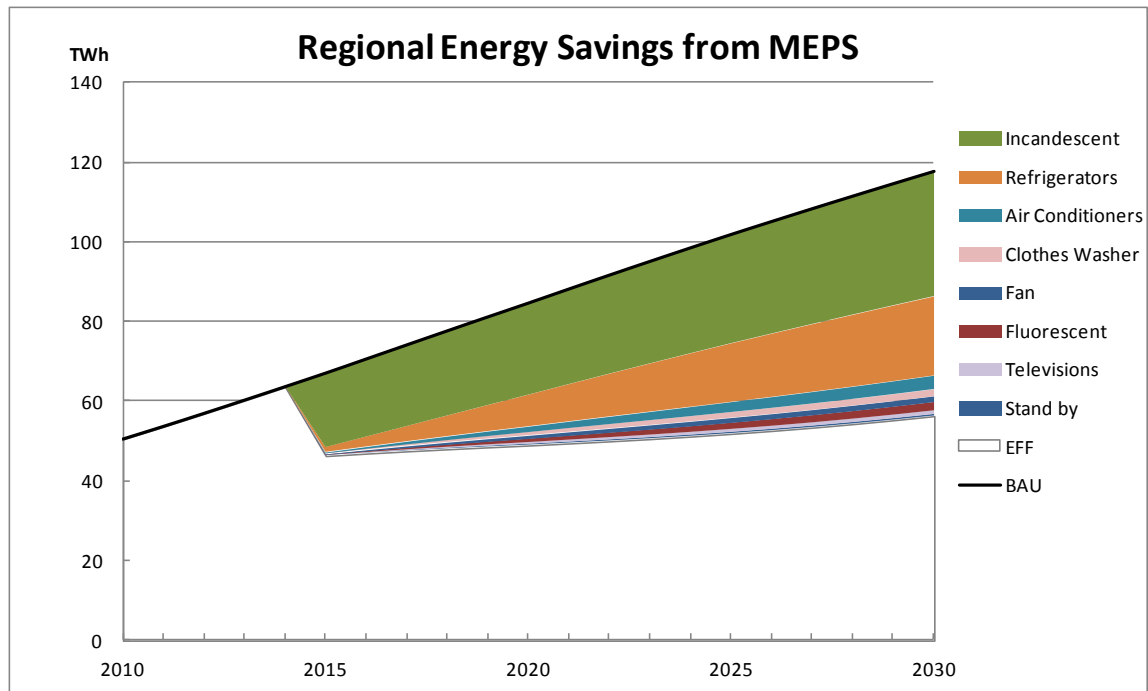
Figure 4. Potential savings from efficiency standards by end use over time.

As shown in the graph below, the largest energy savers are lighting, refrigerators and air conditioners. Energy efficiency regulations on these three end uses provide over 80% of the identified potential savings.
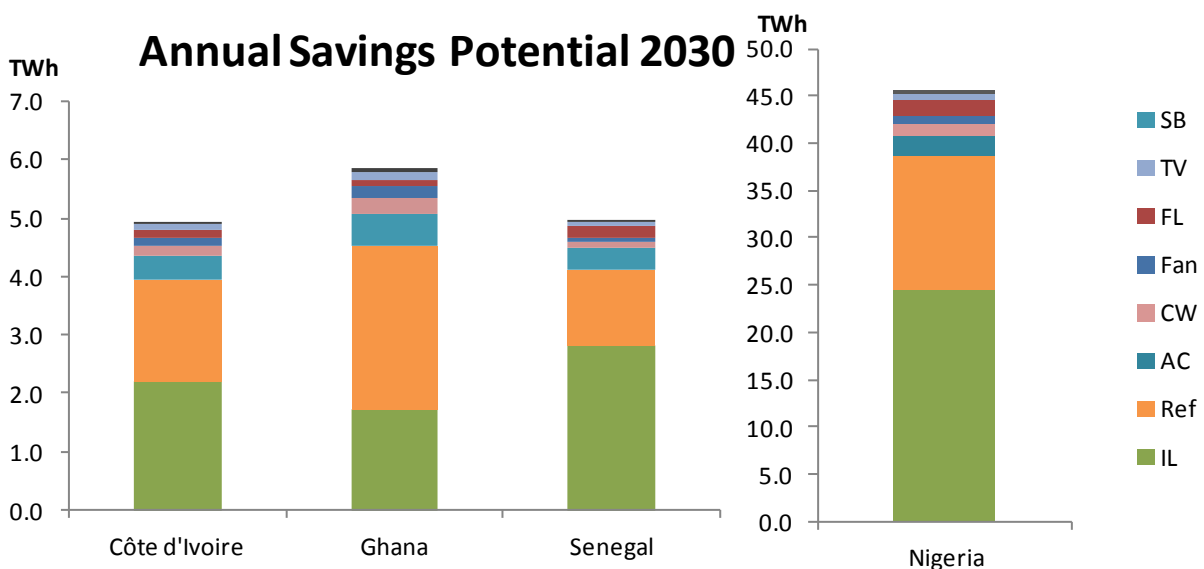
Figure 5. Estimated annual electricity savings in 2030 by end-use for each country modeled.

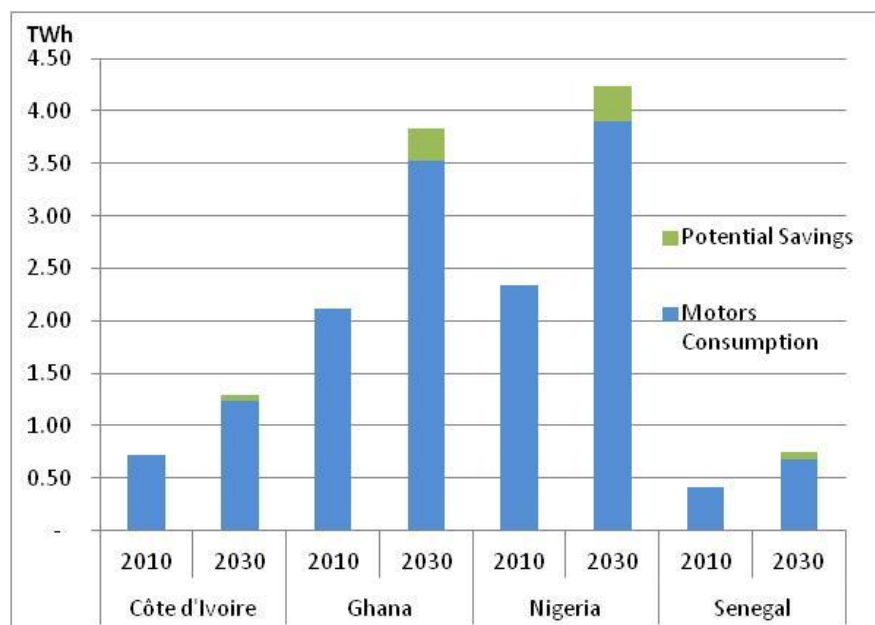The following graph shows the evolution of motors energy consumption between 2010 and 2030 along with the potential savings per country. Savings are small compared to the residential sector. Nigeria has a low reported energy consumption for the industry sector, which contributes to lowering the savings compared to the residential sector.

Figure 6. Potential savings from efficiency standards for motors.

Due to the lack of data in the ECOWAS region, the results presented in this analysis are subject to a sizeable uncertainty. A complete discussion of possible sources of errors is available in McNeil et al. (2012) . The list below summarizes the most important sources of uncertainties:

- Data-driven variables: Field surveys are few, and the sample size is often limited. Market data was for the most part unavailable. As a consequence, international proxies are the best estimate one can make. As a result, energy usage of appliances carries a significant uncertainty.
- Forecast parameters: This type of uncertainty is inherent to prospective analysis as it is virtually impossible to predict the future with high accuracy. Largest effects come from economic development forecast which impacts household income, urbanization, and access to electricity (i.e the main drivers in our appliance diffusion forecast).

Summary Results and Discussion

Table 7 summarizes the savings from the end uses studied, for every country in the ECOWAS region covered in BUENAS.

Table 7 Results Summary

End Use	2010 BAU	2020 BAU		2020 Savings		2030 BAU		2030 Savings	
	TWh	TWh	Growth Rate 2010-2020	TWh	% Red. vs BAU	TWh	Growth Rate 2010-2030	TWh	% Red. vs BAU
Clothes Washers	0.8	3.7	16.4%	0.8	22.6%	6.6	11.0%	1.8	27.1%
Fans	2.0	2.9	3.8%	0.8	26.9%	3.7	3.1%	1.4	38.0%
Fluorescent Ballast	6.1	9.6	4.7%	0.8	8.8%	13.0	3.9%	2.1	16.1%
Residential Lamps	19.3	30.8	4.8%	23.1	75.0%	41.8	4.0%	31.4	75.0%
Refrigerators	12.1	24.2	7.2%	7.9	32.9%	35.4	5.5%	19.9	56.3%
Air Conditioners*	11.5	14.3	2.2%	1.8	12.4%	17.9	2.2%	4.5	24.9%
Standby Power	0.7	0.8	1.9%	0.3	30.1%	1.0	1.9%	0.4	40.4%
Televisions	1.0	1.9	6.7%	0.5	26.1%	2.8	5.2%	1.0	34.6%
Residential Total	**53.5**	**88.3**	**5.1%**	**36.1**	**40.9%**	**122.3**	**4.2%**	**62.4**	**51.0%**
Motors	5.6	7.5	3.0%	0.2	3.0%	10.1	3.0%	0.7	7.4%
Industry Total	**5.6**	**7.5**	**3.0%**	**0.2**	**3.0%**	**10.1**	**3.0%**	**0.7**	**7.4%**
Total	**59.1**	**95.8**	**5.0%**	**36.30**	**37.9%**	**132.4**	**4.1%**	**63.2**	**47.7%**

*Includes commercial applications

A few key results:

- Lighting: This is the biggest saver out of all the products covered. The switch to CFLs provides a 75% improvement over the base case, or 23 TWh by 2020 and 35 TWh by 2030. Also due to the short lifetime of incandescent bulbs, the impact of a regulation that mandates high efficiency bulbs is almost immediate.
- Refrigerators:. A shift from current inefficient unregulated refrigerators to moderately efficient level C refrigerators would provide 20 TWh savings by 2030. This assumes that refrigerators are bought new (or at least comply with the mandatory efficiency level) and that the test procedure accurately describes the field consumption, which could be higher. After lighting, refrigerators have the largest foot print in the BAU, hence we find large potential savings for this end use.
- Air conditioners: While per unit efficiency improvements are high, we find that the penetration of ACs stays low even by 2030 (2.2% growth rate for this end use). Given their high per unit usage, ACs are the 3rd appliance in terms of potential savings.

- Fast uptake of equipment: Most equipment types are forecast to grow at a rate of 3% or more. This is due to low penetration of equipment in the current stock, and a favorable forecast economic growth rate. Because households are buying many appliances for the first time, implementing S&L at this time presents a great opportunity to achieve fast penetration of efficient appliances in the stock (as opposed to waiting for the old stock to retire). As an example, clothes washers have a small foot print and a long lifetime (15 years), and the coming years will see an 11-percent growth rate in that end use.

The set of MEPS modeled in this report would achieve 36 TWh savings by 2020 and 63 TWh by 2030. This represents a reduction in residential electricity demand of 38% for the end uses covered by MEPS by 2020 and 48% by 2030. These policies have for effect to decrease the energy demand annual growth rate from 4.2% to 0.5%. Due to the limited size of the industry sector in the ECOWAS region, savings potential for motors are small compared to other regions of the world (Letschert et al., 2012). Nevertheless, a reduction of 7.5% is achievable by 2030. Because of the fast uptake of new equipment in the households, the ECOWAS region sees great opportunity of savings for MEPS both in term of magnitude and in term of immediate results. Nevertheless, because of the overall poverty of the region, a cost-benefit analysis is crucial in order to protect consumers from financial burdens. In every country, we recommend a careful assessment of the market and performing a technico-economic analysis when designing future energy efficiency policies. This analysis should assess the direct financial impact on the consumers as well as the national financial and energy impacts when considering possible MEPS efficiency levels.

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